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INTERTEMPORAL AND INTERSPATIAL VARIABILITY OF CLIMATE CHANGE ON DRYLAND WINTER WHEAT YIELD TRENDS[1]

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Abstract

The importance of climate (temperature and precipitation) variability on Nebraska dryland winter wheat yield trend is examined. The use of short term (1956-1999) climatic divisional panel data (interspatial) and long term (1909-1999) state time series data (intertemporal) is to address the predictability power of estimating the yield trends accounting for climate variability.

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INTERTEMPORAL AND INTERSPATIAL VARIABILITY OF CLIMATE CHANGE ON DRYLAND WINTER WHEAT YIELD TRENDS

The competitiveness of U.S. agriculture in the world market is influenced by its rate of total factor productivity improvement, internal pricing policies and to a certain extent by unpredictable climate. The U.S. agriculture sector, for the most part, has been evolving and adapting to the prevailing socioeconomic conditions and policies effectively. Recent studies (Adams *et al,* 1999; Darwin, 1999; Darwin *et al*, 1995; Kaiser *et al.*, 1993; Mendelsohn, Nordhaus, and Shaw, 1994) indicate climate induced shifts is likely to influence the adaptation and evolution of the agriculture sector in the long run. However the net effect of climate change on agriculture output is low or negligible, given that agricultural production is likely to increase at higher latitudes where current temperatures are relatively cool and decrease in relatively warm or dry areas with low precipitation.

Even though the overall effects on agricultural production is negligible, the recent increased variability in temperature and precipitation at the disaggregate level or for that matter at the climatic divisions within each state is likely to influence the patterns of regional crop yield trends. The crop yield trends can be identified with changing production practices (that includes new hybrids, development of disease and pest resistant varieties, and government policy), with variability in climate variables like precipitation and temperature having obvious effects. As a first step towards analyzing the aggregate effects of climate on agriculture sector, a statistical analysis of crop-specific yield trends reflecting the direct response to the elements of the climate needs to be conducted.

Statistical analyses will be conducted to assess and evaluate the yield trends at the state-level with longer time series (1909-1999) and at the climatic divisional-level with shorter panel data (1956-1999) using Nebraska winter wheat dryland yields. Further the analyses are also examined for autocorrelation and heteroskedasticity due to its potential implications on the results. The procedures will build on the statistical framework developed by the Atwood et al (1997), extensively for crop insurance at the farm and regional crop yield trends for major crops. The statistical procedures developed by Atwood et al has been well established and further used in crop insurance studies (Atwood and Shaik, 1999; Atwood, Shaik and Watts, 1999). This statistical framework would provide the basis to advance the yield trend analysis related to climate change. First, the statistical approach addresses the construction of the divisional-level crop yields based on the county data to provide a through assessment of the climate variability. Second, it would provide the basis to incorporate the element of weather-related risk and uncertainty into the crop yield trends using shorter divisional-level panel data versus the longer state-level data. Third, the direct impacts of climate on the trends can be used in comparative static models and/or in econometric estimation to examine the impacts on farm economic structure. Finally, provides basis to adjust the total factor productivity measures for climate change based on the state-level crop yields.

Existing and recent literature (Gard, 1980; Kaiser et al, 1993, 1995; Nordhus, 1994; Schimmelpfenning, 1996; Mendelsohn and Neuman, 1999) have addressed the issue of potential effects on yield-specific trends, input use patterns and output production mix based on 1) simulated site-specific crop growth models, and 2) aggregate state level time series data and 3) examined the effects of elevated CO_2 concentration on crop yields trends. Teigon and Thomas, 1995 conducted extensive state level analysis of the influence of temperature and precipitation on crop-specific trends. Further the nonlinear response to components of the weather, turning relatively symmetric temperature and precipitation variables into skewed component of the yield distribution have been modeled by Teigon (1991, 1992). He also showed the residuals leftover once weather has been appropriately modeled appear to be symmetric white noise. The state level analysis for the variability of climate changes is too aggregated, in the sense the interspatial variability might be eclipsed due to the use of state-level data. Using a long-term state-level yield data accounts for the intertemporal variability.

In this paper we examine and evaluate the effects of climate on Nebraska dryland winter wheat yield trends, focusing primarily on the linear and separable influence of technology (time trend) and climate (temperature, precipitation and allowing interaction between temperature and precipitation) induced changes. The uncertainties associated with climate, particularly at the state and divisional level addresses the predictability power of using short-term divisional-level panel data (1956-1999) and long-term state-level time series data (1909-1999) on yields. The next section presents the models estimated to examine the interspatial (using divisional level panel data) and intertemporal (using state-level time series data) variability of dryland winter wheat yield trends in Nebraska. Also included in this section is the construction of divisional yields from the county data. The empirical application and the results will be presented in the third section followed by summary and conclusions in the last section.

Modeling Yield Trends and Construction of the Data

Traditionally aggregate time series data are used to examine and estimate the trends in crop yields (y_t for time series and $y_{i,t}$ for panel data). The assumptions of linear and separable technology (time trend) and climate (temperature, precipitation and allowing interaction between temperature and precipitation) induced changes influencing the trend in crop yields can be represented as:

(1) $y_t = F\left[f(C_i), f(t) \right]$

where for year *t*, $f(C_i)$ represents the yield effects of temperature, precipitation, and the interaction between temperature and precipitation; i represents the vegetative (*t-1* for the months of September through December, and year *t* for the months of January through April) or reproductive (year *t* for the months of May and June) or dormancy (*t-1* for the month of December and year *t* for the months of January and February) stages, $f(t)$ represents the technological (time trend) changes and a disturbance term assumed to be a random variable with mean zero and constant variance. As indicated above, the crop yield is likely to be influenced by the mean temperature and total precipitation across the three stages (vegetative, reproductive and dormancy periods) independently.

The estimation of the yield trends (equation (1)) can be modeled as time series regression or panel regression models. This can be represented as:

(2*a*) $$y_t = \alpha_0 + \sum_{k=1}^{5} \beta_{k,t} x_{k,t} + \varepsilon_t$$ time series model

(2*b*) $$y_{i,t} = \alpha_0 + \sum_{k=1}^{5} \beta_{k,it} x_{k,it} + \varepsilon_{it}$$ panel model

where $x_{1,t}$ =technology (time trend), $x_{2,t}$ =mean temperature during the vegetative stage, $x_{3,t}$ =total precipitation during the vegetative stage, $x_{4,t}$ =interaction term of mean temperature and total precipitation during the reproductive stage, $x_{5,t}$ =the mean temperature during the dormancy stage and finally i represents the eight climatic divisions of Nebraska.

To develop a distribution as well as a response of technology (time trend) and the increased variability in temperature and precipitation on expected crop yield trends, two sets of statistical analysis are conducted. Careful attention is given to examine the presence of heteroskedasticity in the time series model, with greater importance given to cross-section and over time heteroskedasticity, autocorrelation and correlation across the climate divisions in the panel model. Apart from examining the predictability power of the crop yield trends we also estimate the parameter coefficients of technology and climate variables from the two models (time series versus panel data).

In the first set of analyses, the long-term state-level time series data (1909-1999) and short-term divisional-level panel data (1956-1999) are used in the two regression models to compare the coefficient estimates of technology and climate variables. The second set of analysis involves the use of only climate division's data to examine the predictability power of yield trends accounting for technology and climate variability. The predicted expected yield trends for each of the climate divisions are estimated using time series regression model and panel regression model to examine the intertemporal and interspatial variability.

CONSTRUCTION OF DIVISIONAL YIELD DATA

The state of Nebraska has been divided by the National Oceanic and Atmospheric Administration (NOAA) into eight climatic divisions, Panhandle (1), North Central (2), Northeast (3), Central (5), East Central (6), Southwest (7), South Central (8) and Southeast (9). The different climatic divisions are represented in Figure 1. The monthly temperature and precipitation data is available from NOAA at the state and the climatic divisional level. Given the availability of divisional data, the county level wheat yields from National Agricultural Statistical Service (NASS) are used in the construction of divisional level Nebraska dryland winter wheat yields. The use of planted yields truly reflects the potential impacts of climate change on the yields rather then the harvested yields. The county and state-level dryland winter wheat yields are obtained from the NASS. The data types (and notation) can be defined as follows for state and divisions:

(3) State yields $\equiv y_t$

and

$$(4a) \quad \text{County Yields} = y_t^C$$

$$(4b) \quad \text{Divisional Yields} = y_t^D = \sum_{c=1}^{C} a_{c,t}\, y_{c,t}^C, \ \sum_{c=1}^{C} a_{c,t} = 1$$

$$(4c) \quad \text{Panel data} = y_{i,t} = \sum_{i=1}^{8} y_{i,t}^D$$

where the t in equation (3) ranges from 1909-1999 and in equations (4a, 4b, and 4c) ranges from 1956-1999.

In the above expressions, we have identical number of years at the county and division-level, but longer time series data at the state level. The divisional data is acreage weighted county yields for each climatic division in the state of Nebraska. The panel data consists of the divisional yield recorded in each of the eight climatic divisions across the whole state. The panel data is used to assess and evaluate the likely changes in winter wheat dryland yield trends due to temperature and precipitation. Further the variations in the panel model are examined and the choice of the panel model is made using the likelihood ratio test static.

Empirical Application and Results

We examine and evaluate the effects of technology (time trend) and climate (temperature and precipitation) induced changes on the expected dryland winter wheat yield trends. The availability of monthly temperature and precipitation data at the state and climatic divisional level allows us to model the influence of the stages of growth on yield trends. For dryland winter wheat in Nebraska, the vegetative stage is most significant, however weather from the reproductive and the dormancy stages are also examined in the regression models. In general, the total precipitation (mean temperature) during the most important vegetative stage should have a positive (negative) effect on the yield. While during the less important reproductive (dormancy) stage, the interaction of mean temperature and total precipitation (mean temperature) should have a negative (positive) influence on the yields.

In Figure 2, the variance rather than the mean of the planted yields and the climate variables for the three stages of growth are presented for the individual divisions, all divisions and the state data. In Table 1 the coefficient estimates of technology (time trend) and climate variables from the panel regression model (using data from 1957-1999) and the time series regression model (using data from 1910-1999) are presented. Important of all, the expected yield trends from the individual divisional time series model and the panel model accounting for time trend and climate changes are estimated for all the eight climate divisions in Nebraska. However we present the actual planted yield, expected yields estimated from both models in Table 2 and graphically in Figure 3 for Panhandle climate division[3].

[3] Figure for a single climate division (Panhandle) is present to demonstrate the potential differences in the expected yield trends estimated from the time series model (only the intertemporal variability) and the panel model (intertemporal and interspatial variability). However similar differences in the yield trends are observed for the remaining 7 climate divisions and hence not presented, but can be obtained from the contact author.

The coefficient estimates from the time series and the panel model presented in Table 1 indicate identical signs on the independent variables with the exception of mean temperature during the dormancy stage. The time series model is examined for the presence of autocorrelation based on the Durbin Watson test statistic and the heteroskedasticity based on the Glejser test. In panel data, the heteroskedasticity is examined by regressing the pooled residuals from cross-section correlated and time-wise autoregressive model on technology (time trend). However we were not able to reject the presence of homoskedasticity in the panel model.

Even though the signs on the coefficient estimates from the time series and panel model are identical, the expected yield trends from the two models accounting for technology (time trend) and climate (temperature, precipitation and interaction of temperature and precipitation) are estimated in the second set of analysis. The estimation of panel data (incorporates interspatial and intertemporal variability) and time series (incorporates only the intertemporal variability) would allow to examine the predictability power on yield trends. To be specific, the predicted yield trends for the time period 1957-1999 estimated from the panel model are compared to individually estimated yield trends from the time series model for each climatic division. The predicted wheat yields from the two models and the actual yield for Panhandle climatic division is graphically presented in Figure 3 to examine the impacts of intertemporal and interspatial variability on the expected wheat yield trends. The predicted yield trends estimated from the time series model and panel model exhibit differences even though, the presence of autocorrelation and heteroskedasticity are independently accounted in the both the models. Similar kind of difference has been exhibit in the remaining seven climate divisions. The difference in the yield trends might be due to the interspatial and intertemporal variability. The time series model accounts for only the intertemporal variability compared to the interspatial and intertemporal variability accounted in the panel model. Further with panel data, a large number of observations are present, increasing the degrees of freedom and efficiency of econometric estimates.

Overall the statistical analysis conducted with the use of shorter divisional-level yield series (1956-1999) and longer state-level yield series (1909-1999), indicate differential impacts of the expected wheat yield trends. Even though the coefficient estimates from the time series model and the panel model do not exhibit difference in the signs, the interspatial and intertemporal variability seem to influence the winter wheat dryland yield trends in Nebraska.

Conclusions

This paper examines the interspatial and intertemporal variability due to climate change and time trend with the use of shorter divisional-level yield series (1956-1999) and longer state-level yield series (1909-1999) respectively using Nebraska dryland winter wheat. Even though the signs on the coefficient estimates from the state level time series model and divisional level panel model do not exhibit difference, the expected wheat yield trends from the two models accounting for time trend and climate changes are quite different. To be specific the predicted wheat yields for each of the climatic division from the panel model compared to the individually estimated time series model for each climate division for the same time period, 1956-1999 indicate different yield trends.

Further research needs to be explored allowing for interaction between trend and climate variables as well as exhaustive examination of the climate variable probability distributions.

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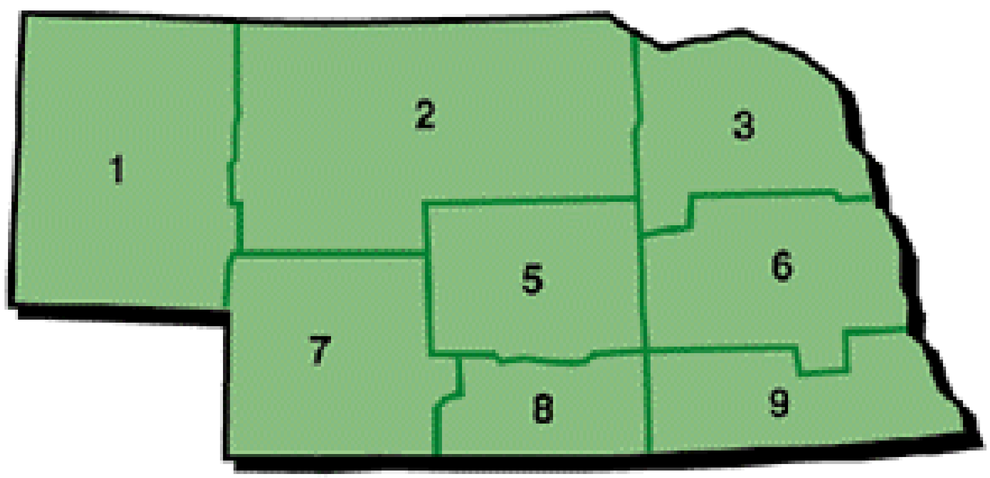
Table 1. Coefficient Estimates from Time series and Panel Regression Models.

Variables	Wheat Yield response to Climate variables and trend	
	Time series Model (Time period, 1910-1999)	**Panel Model (Time period, 1957-1999)**
Intercept	-537.07 (-12.95)	-292.84 (-2.505)
Technology (time trend)	0.3045 (14.21)	0.1538 (2.60)
Temperature (vegetative stage)	0.1490 (0.275)	0.1173 (0.411)
Precipitation (vegetative stage)	1.0237 (4.027)	0.3415 (3.626)
Temp*Precip (reproductive stage)	-0.00637 (-1.309)	-0.003212 (-1.651)
Temperature (dormancy Stage)	0.0348 (0.126)	0.4043 (-2.430)

Figure 1. The Major Climatic Divisions in Nebraska



Where

1	Panhandle
2	North Central
3	Northeast
5	Central
6	East Central
7	Southwest
8	South Central
9	Southeast

Figure 2. Variance of Divisional (1957-1999) and State (1910-1999) Level Yields, Precipitation and Temperature for Various Stages of Growth

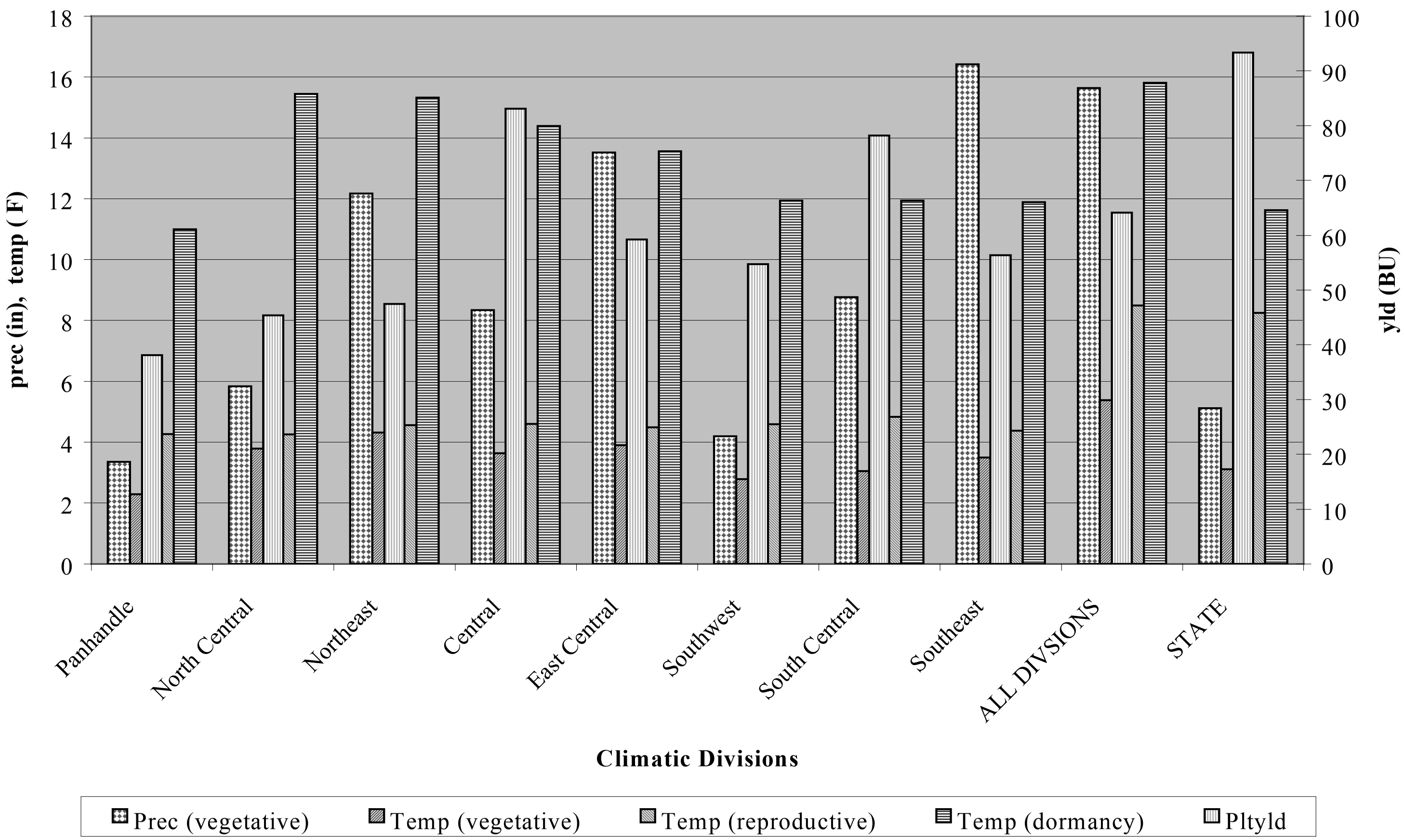


Figure 3. Comparison of Expected Winter Wheat Dryland Yield Trends